II. Listing of Claims

1. (Currently Amended) A method of model-based fault detection for a vehicle steer-by-wire system, the method comprising:

providing a steer-by-wire controlled plant with electric motor actuators, sensors, and other electrical and mechanical components and assembly

providing a steer-by-wire controller for the steer-by-wire controlled plant to implement ~~the~~ a steer-by-wire closed-loop system control;

providing a steer-by-wire fault detection unit in electrical communication with steer-by-wire controlled plant and the steer-by-wire controller to detect faults of the steer-by-wire controlled plant;

receiving input and output signals from the steer-by-wire controlled plant and vehicle signals from the vehicle;

providing a residual generator in the steer-by-wire fault detection unit based on ~~the~~ a mathematical model of steer-by-wire controlled plant without any fault in the controlled plant to implement ~~the~~ an estimation for input signals, output signals, and states of the steer-by-wire controlled plant;

generating a series of residual signals form ~~the~~ a residual generator representing the difference between the received measurement signals from the steer-by-wire controlled plant and the estimated signals from residual generator;

providing a decision-making unit in the steer-by-wire fault detection unit based on the received residual signals from the residual generator and fault test rules; and

generating a fault decision signal to determine the fault occurrence in sensors, actuators, and the steer-by-wire controlled plant with other electro-mechanical components.

2. (Original) The method of Claim 1 wherein the stage of detecting faults of the steer-by-wire controlled plant includes:

generating residual signals; and

making decision to determine whether any faults have occurred by applying a fault test rule for residual signals.

3. (Original) The method of Claim 1 wherein the steer-by-wire controlled plant receives control command signals from the steer-by-wire controller and generates wheel angle measurement signals, and wherein the steer-by-wire controller generates the control command signals which are received by the steer-by-wire control plant as the input command signals.

4. (Currently Amended) The method of Claim 1 wherein the model-based fault detection applies a mathematical model of the steer-by-wire controlled plant to implement a consistency check between ~~the~~ model variables and estimated variables of the actual steer-by-wire system to infer if fault occurs and which components fail.

5. (Original) The method of Claim 4 wherein a robust mode-based fault detection is implemented for a steer-by-wire system under the influence of system uncertainty and nonlinearity of the steer-by-wire controlled plant.

6. (Currently Amended) The method of Claim 5 wherein the uncertainty and nonlinearity of the steer-by-wire controlled plant includes dynamics change with road conditions, vehicle loads, road-tire friction, electric motor-based actuator and assembly dynamics, vehicle dynamics and external circumstances, and the modeling errors of the mathematical model of the steer-by-wire controlled plant.

7. (Currently Amended) The method of Claim 4 wherein the steer-by-wire controlled plant without faults under the influence of system uncertainty and nonlinearity is modeled as

$$\dot{x} = (A(v) + \Delta A(v))x + (B_1(v) + \Delta B_1(v))d + B_2(v)u$$
$$y = (C_2(v) + \Delta C_2(v))x + (D_{21}(v) + \Delta D_{21}(v))d$$
$$z = C_1(v)x,$$

where $x \in R^n$ is a state variable, $y \in R^p$ is a measured output, $z \in R^r$ is a linear combination of state variables to be detected, $d \in R^m$ is a disturbance, u is a control input, $A(v)$, $B_1(v)$, $B_2(v)$, $C_1(v)$, $C_2(v)$, $[[D_{12}(v)]]$ and $D_{21}(v)$ are matrices of

dimensions to describe a nominal system, $\Delta A(v)$, $\Delta B_1(v)$, $\Delta C_2(v)$ and $\Delta D_{21}(v)$ represent parameter uncertainties, and v represents vehicle speed.

8. (Original) The method of Claim 4 wherein a robust fault detection method using the robust gain scheduling H^∞ fault detector is implemented based on the mathematical model of steer-by-wire controlled plant under the influence of system uncertainty and nonlinearity to derive a series residual signal.

9. (Original) The method of Claim 8 wherein the robust gain scheduling H^∞ fault detector is given by

$$\dot{\hat{x}} = A(v)\hat{x} + B_2(v)u + F(v)(y - C_2(v)\hat{x})$$
$$\hat{z} = C_1(v)\hat{x},$$

where gain of $F(v)$ is scheduled as a function of vehicle speed and $\hat{z} = C_1(v)\hat{x}$ is an estimation of the linear combination of state variables to be detected.

10. (Original) The method of Claim 1 wherein the residual signal of residual generator based on the robust gain scheduling H^∞ fault detector is expressed by:

$$\gamma = z - \hat{z},$$

wherein the residual signal is the difference between the output signal $\hat{z}$ of the robust gain scheduling H^∞ fault detector based on the estimation for the variable z and the real measurement signal z.

11. (Original) The method of Claim 10 wherein the residual is robust with respect to the model uncertainty, external noise and dynamic gain change, and is sensitive to faults occurrence in the steer-by-wire controlled plant.

12. (Original) The method of Claim 1 wherein a decision-making unit receives residual signal γ from the residual generator, and generates a fault decision signal to determine the fault occurrence in the steer-by-wire controlled plant by applying the fault test rules.

13. (Currently Amended) The method of Claim 12 wherein the decision process may include a threshold test on the instantaneous values or moving averages of the residuals expressed by:

$$\gamma(t) < \lambda(d,\Delta,v)\text{; no fault occurs, } f = 0$$

$$\gamma(t) \geq \lambda(d,\Delta,v)\text{; fault occurs, } f \neq 0.$$

where $\lambda(d,\Delta,v)$ is a threshold depending on the external noise d, the model uncertainty Δ and the dependent variable [[v]] v resulting in gain changes of the steer-by-wire controlled plant dynamics, and *f* represents a fault.

14. (Original) The method of Claim 1 wherein the faulted steer-by-wire controlled plant models are described for faults occurred in the sensor, actuator, and steer-by-wire controlled plant itself and residual signals are generated from the residual generator based on the robust gain scheduling H^{∞} fault detector.

15. (Original) The method of Claim 1 wherein the fault detection unit receives output signals and input signals of steer-by-wire controlled plant including road wheel angles, steering wheel angle, controller command signals, vehicle speed signal and possible other vehicle signals.

16. (Original) The method of Claim 1 wherein the fault detection unit is a steering wheel force feedback fault detection unit for detecting faults occurred in the steering wheel force feedback controlled plant including sensors, actuators and the controlled plant itself.

17. (Original) The method of Claim 1 wherein the fault detection unit is a road wheel actuation fault detection unit for detecting faults occurred in the road wheel actuation controlled plant including sensors, actuators and the controlled plant itself.

18. (Original) The method of Claim 1 wherein a series residuals may be generated which each residual indicates a different fault to achieve fault isolation.

19. (Currently Amended) A system of model-based fault detection for a vehicle steer-by-wire system, the system comprising:

a steer-by-wire controlled plant with electric motor actuators, sensors, and other electrical and mechanical components and assembly;

a steer-by-wire controller for the steer-by-wire controlled plant to implement [[the]] a steer-by-wire system feedback control;

a steer-by-wire fault detection unit in electrical communication with the steer-by-wire controlled plant and the steer-by-wire controller to detect faults of the steer-by-wire controlled plant, the fault detection unit being configured to receive input and output signals from the steer-by-wire controlled plant and vehicle signals from the vehicle;

a residual signal generator in the steer-by-wire fault detection unit based on ~~the~~ a mathematical model of steer-by-wire controlled plant without any fault in the controlled plant; and

a decision-making unit in the steer-by-wire fault detection unit to examine residuals and to determine if any faults have occurred according to the a fault decision rule.

20. (Original) The system of Claim 19 wherein the fault detection unit receives output signals and input signals of steer-by-wire controlled plant including road wheel angles, steering wheel angle, controller command signals, vehicle speed signal and possible other vehicle signals.

21. (Original) The system of Claim 19 wherein the fault detection unit generates the fault decision signals for detecting faults in the steer-by-wire system including sensors, actuators and the steer-by-wire controlled plant itself.